AMELIE

An Axion Modulation hELIoscope Experiment idea

J. Galan
University of Zaragoza
11th Patras Workshop on Axions, WIMPs and WISPs

Pionering helioscope searches were using stationary helioscopes

VOLUME 69, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1992

Search for Solar Axions

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(Received 22 May 1992)

1992

First helioscope

Stationary helioscope (a la Sikivie)
Taking data when magnet pipe is on Sun field of view.

$g_{ag} < 3.6 \times 10^{-9}$ GeV^{-1} for $m_a < 30$meV

Also running using low pressure buffer gas

Experimental Search for Solar Axions via Coherent Primakoff Conversion in a Germanium Spectrometer

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(Received 17 June 1998)

1997

First Underground helioscopes

COSME, SOLAX, CDMS, DAMA
These experiments give similar upper limits for the coupling

$g_{ag} < 1.7\text{-}2.7 \times 10^{-9}$ GeV^{-1} $m_a < 1$keV

The helioscope reference papers

VOLUME 51, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1983

1983

Experimental Tests of the "Invisible" Axion

P. Sikivie
Physics Department, University of Florida, Gainesville, Florida 32611
(Received 13 July 1983)

THIRD SERIES, VOLUME 39, NUMBER 8 15 APRIL 1989

1989

Design for a practical laboratory detector for solar axions

K. van Bibber
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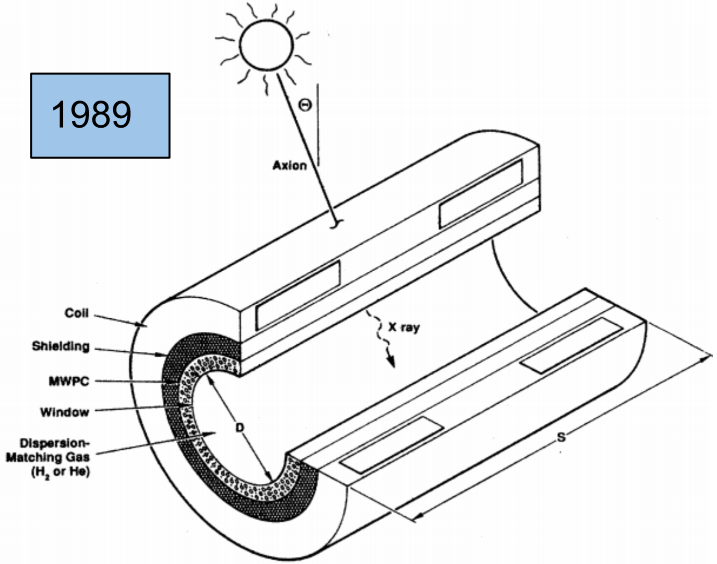
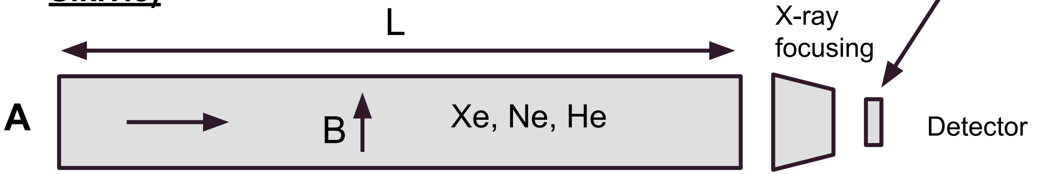
(Received 19 September 1988)



Two helioscope techniques for axion detection

Photons detected **at the end** of magnet bore

Tracking Helioscope method (CAST,IAXO, Sikivie)

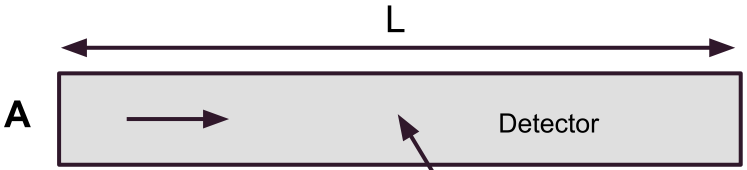


Number of photons found at a distance L

$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\left[1 + e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos(qL)\right]$$

Starts to be competitive for higher masses ~eV

Absorption Helioscope Method



Number of photons absorbed along a distance L

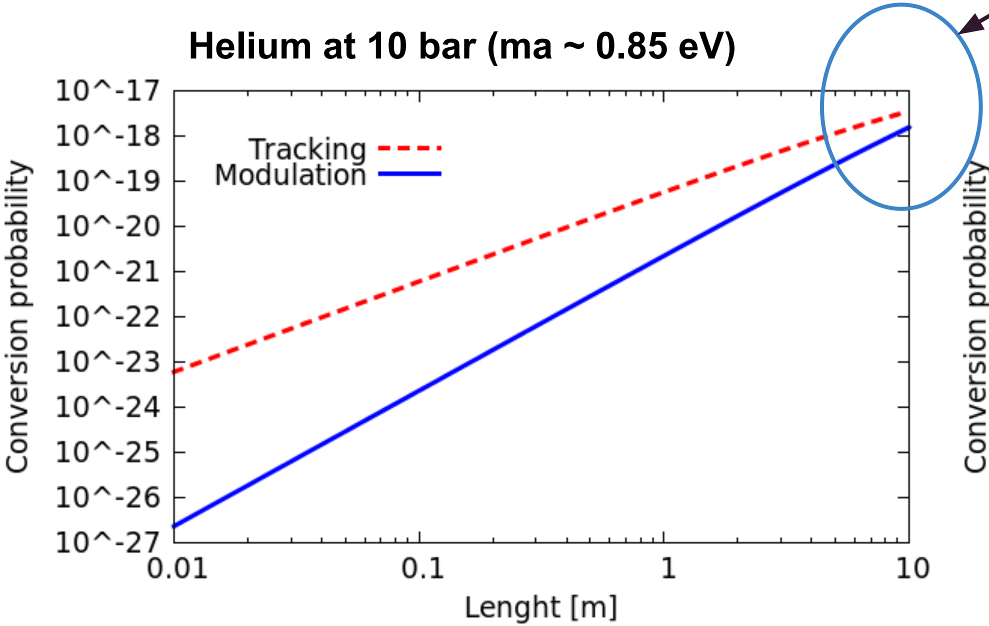
$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\Gamma L$$

Photons detected **inside** the magnet bore

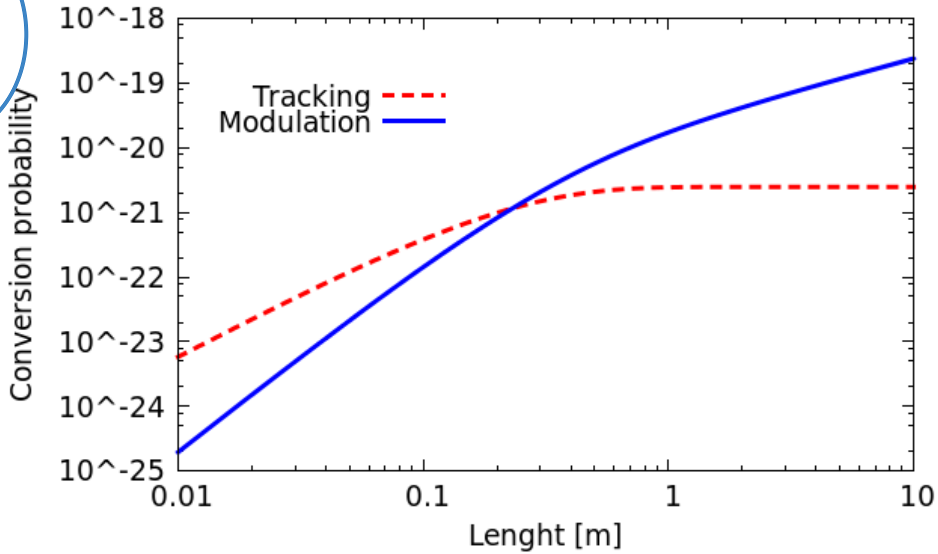
Absorbed or transmitted photon component

Corresponding to latest CAST pressure settings

Helium at 10 bar (ma ~ 0.85 eV)



Xenon at 100 mbar (ma ~ 0.4 eV)



A magnetic TPC for an helioscope proposal

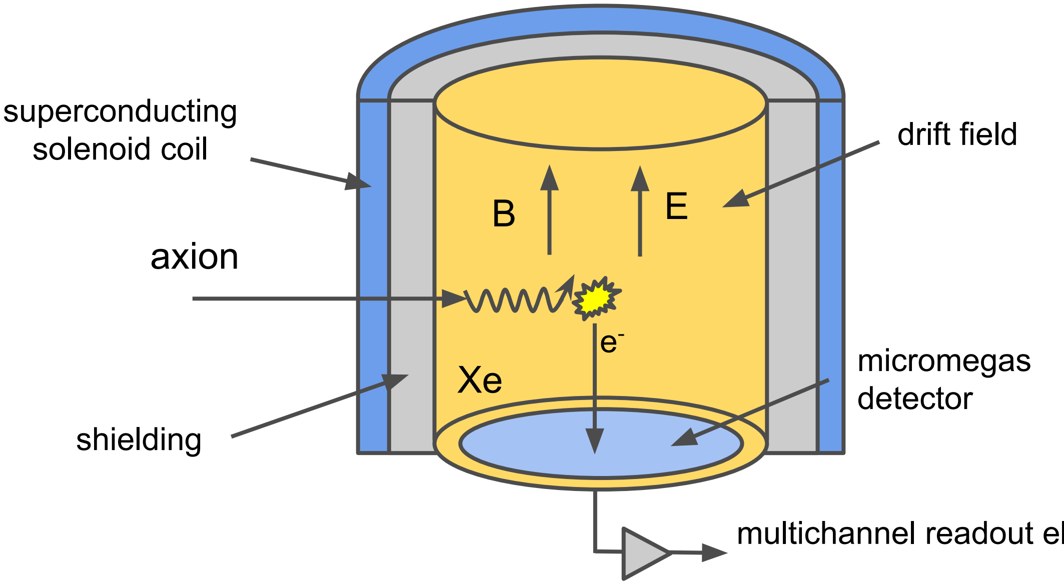
The axion-photon **component transmitted** goes typically as L^2, thus **a long pipe is usually the best suitable geometry**.

However, for the axion-photon **component absorbed** is just proportional to L, thus (for high Γ) we can use **any volume geometry** (in principle).

$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\Gamma L$$

This technique is especially interesting if
ΓL >> 1.
High Z gases (for many reasons).

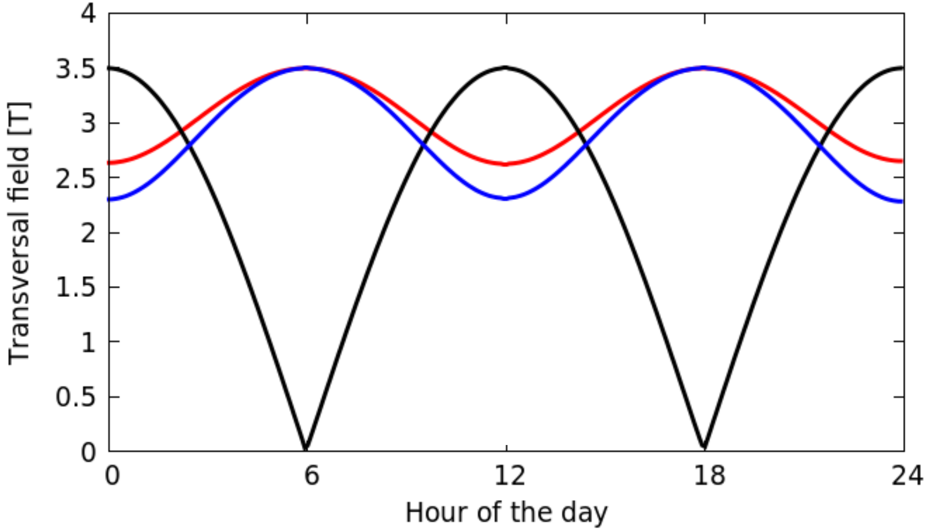
A possible conceptual TPC-magnet design



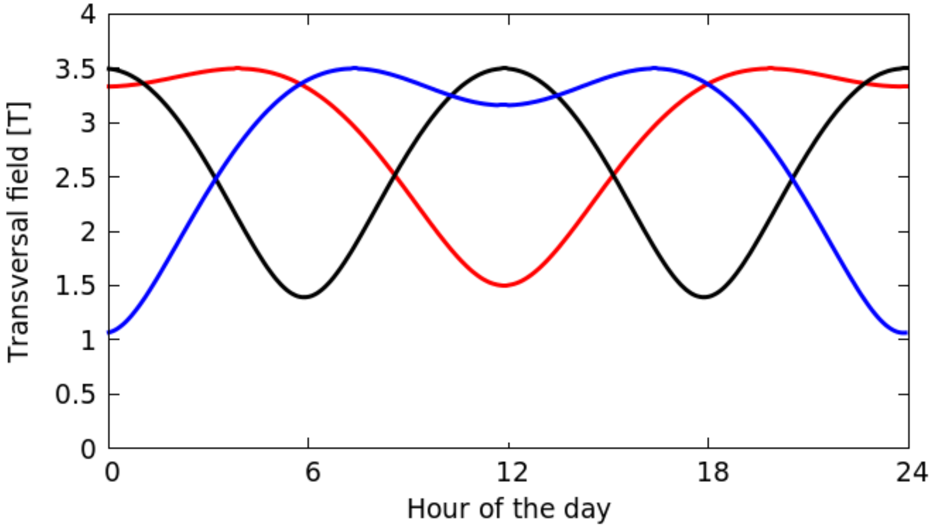
Daily modulation due to Earth rotation

The effective magnetic field for axion-photon conversion modulates.
We must consider only the transversal component to the axion propagation direction that changes along the day.

21st of March

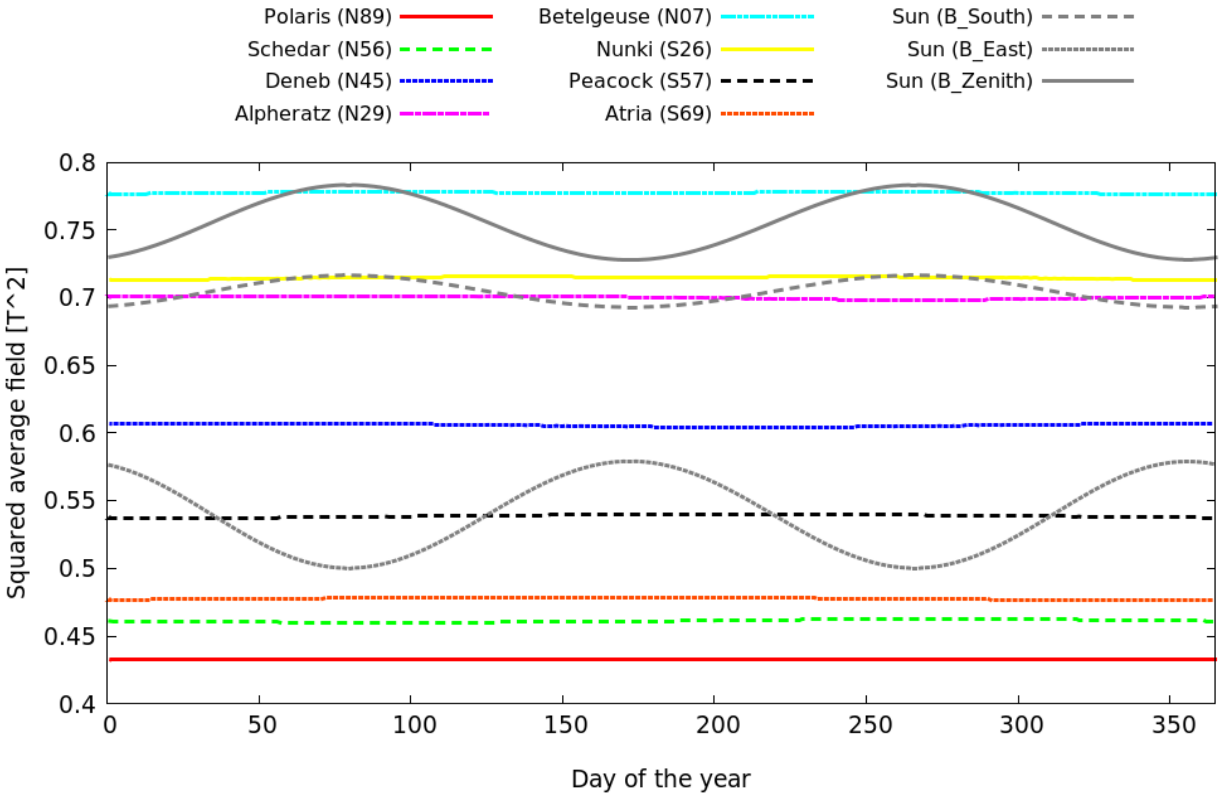


21st of June



Towards Zenith
Towards East
Towards South

Annual axion signal modulation (daily averaged)



3 Different TPC magnetic field orientations are shown for Solar axions.

Effective field **~0.75 B^2** for a <u>field perpendicular to the ground.</u>

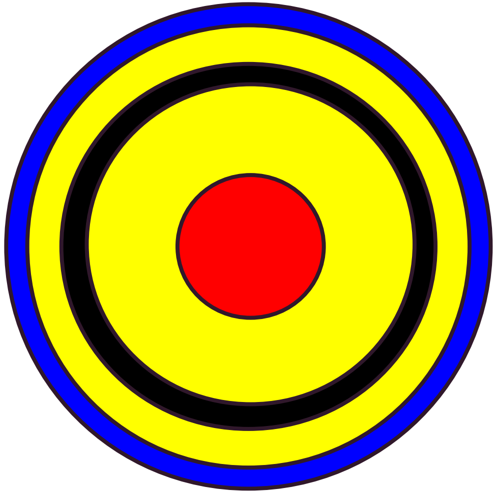
Different sky positions are also shown. Negligible effect on annual modulation.

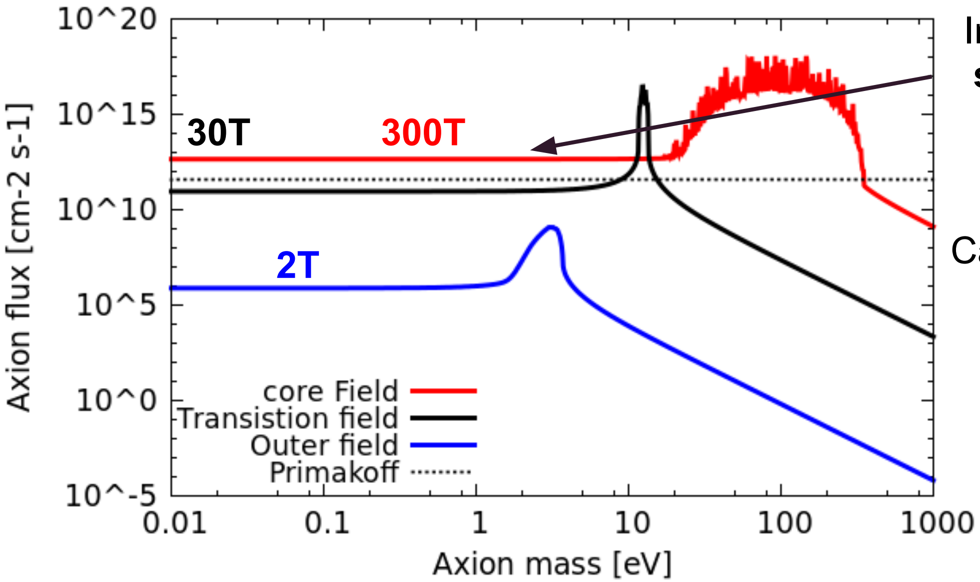
This **Annual** modulating pattern is <u>exclusive of the Sun.</u>

Full angular view sensitivity (4π)

S.Couvidat, S. Turck-Chieze, A. Kosovichev, APJ 599, 1434 (2003) → Magnetic fields

The Sun magnetic fields





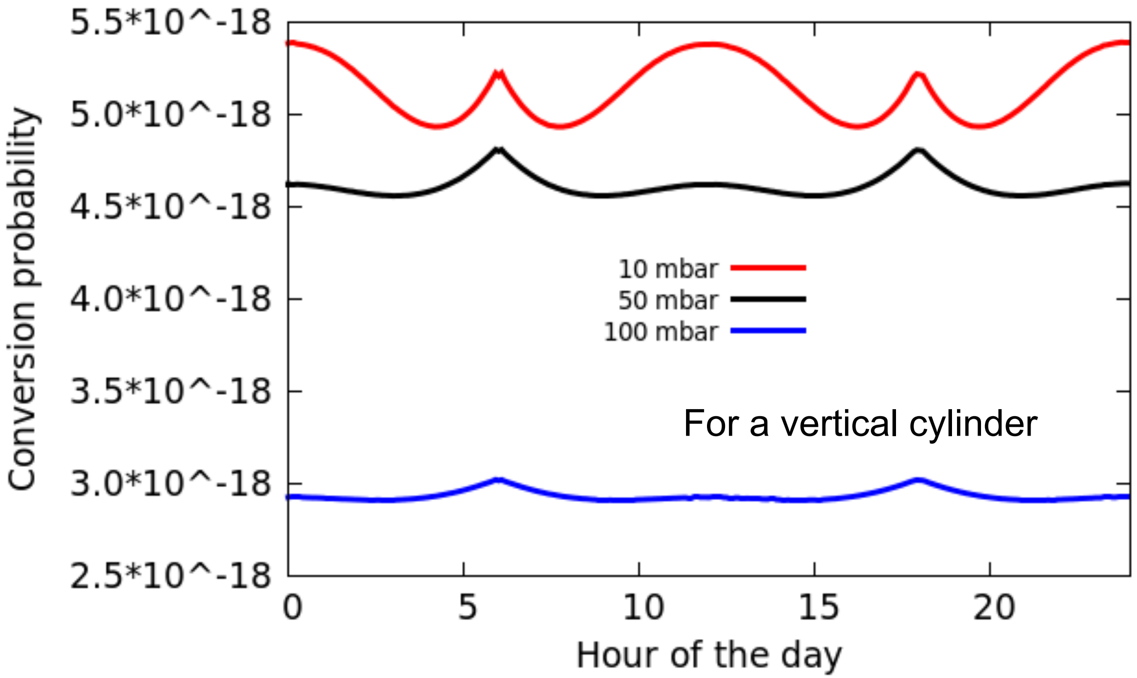
In the core **3000T are still allowed** without effect on Solar observables.

Calculation considering factor 10 reduction

300T

Effective conversion probability (Geometrical factor)

There is a geometrical factor to consider due to the different coherence lengths traversing the chamber.



Conversion probability is reduced when ΓL is not >> 1. And this relation does not apply

$$P_\gamma = \frac{(B/2M)^2}{q^2 + \Gamma^2/4}\Gamma L$$

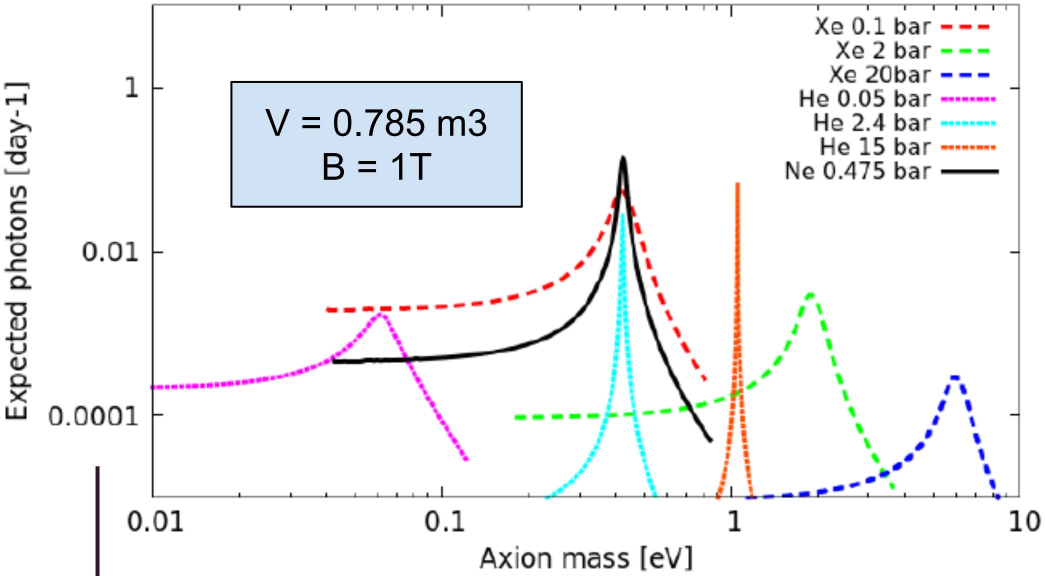
Efficiency loss in Xenon

10 mbar	21.5%
50 mbar	11.9%
100 mbar	6.9%
500 mbar	1.4%
5 bar	0.13%

Small diurnal effect and negligible annual variations

Conversion probability resonances

Conversion probability resonances at different gases and mixtures

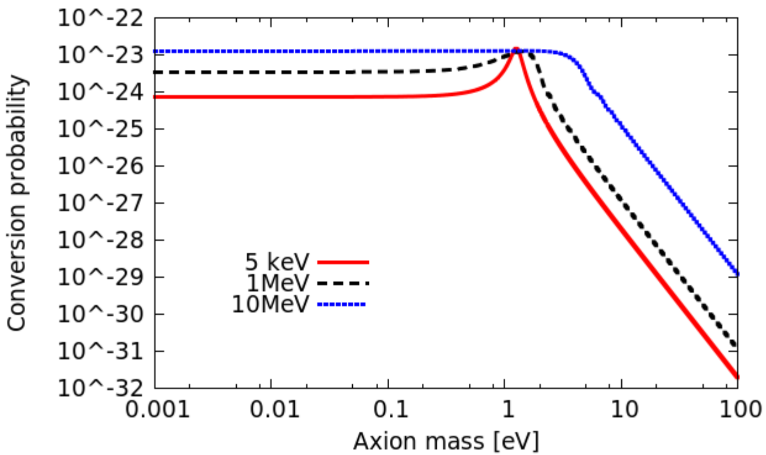


Very low expected rate.
Very low background large volume TPC required.

Effective axion mass related to gas conditions

$$m_\gamma^2 = 4\pi r_o (N_A / A m_u) \rho f_1$$

Conversion probability for high energy axion (~MeV)

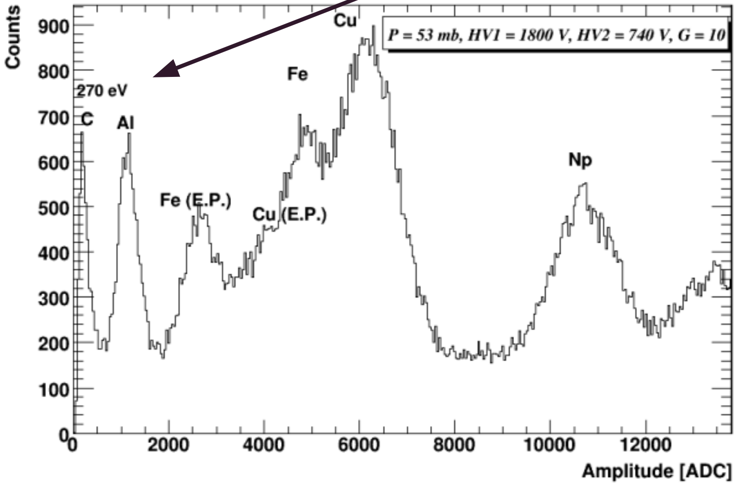


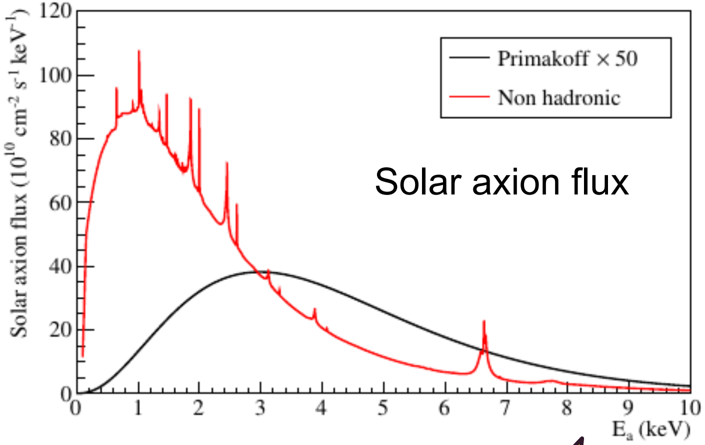
State of the art in low background large volume TPCs

SEDINE spherical TPC
running at LSM
Record background levels actually
around 10 cpd/m³/keV

Large volume and ultra-low background

Ultra low energy threshold TPC





Solar axion flux

T-REX DM project at University of Zaragoza, similar background levels expected.

Convinced that there is room for improvement on background levels.

See F.J. Iguaz talk at this Workshop

AMELIE Search sensitivity prospects

Run conditions (Xenon)

16 Pressure steps

from 10mbar to 5bar

150 days per step ~ 8 years

B = 5T

Background

AMELIE-PROTO : 1 cpd/m^3/keV

AMELIE : 0.1 cpd/m^3/keV

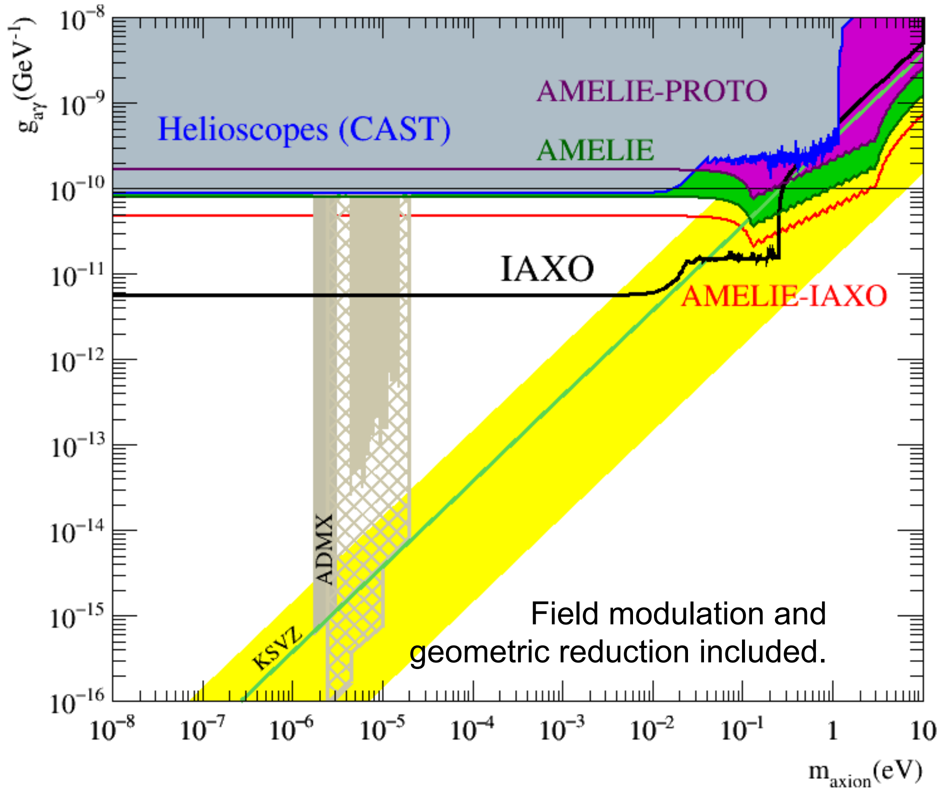
AMELIE-IAXO : 0.1 cpd/m^3/keV

Volume

AMELIE-PROTO : 21 dm^3

AMELIE : 0.785 m^3

AMELIE-IAXO : 45.23 m^3



Conclusions

- An independent technique for solar axion searches is foreseen.
- Full angular sensitivity (allows to observe the full solar disk + other exotic sources). Also not high accuracy alignment required.
- Improved gas density stability and broader axion mass coverage with a single setting. Leading to a simplified data taking process.
- Enables searches to very low energies (few ~100eV). Since there is no separation between detector and conversion volume.
- It would allow to proof KSVZ axions above 50meV-100meV.
- Rare event searches underground with TPCs are becoming very exciting, using a magnetic field will make these searches even more interesting.

Backup Slides

Production probability in a magnetic gas

$$i\partial_z \begin{pmatrix} A(z) \\ a(z) \end{pmatrix} = \begin{pmatrix} E_a - m_\gamma^2/2E_a - i\Gamma/2 & B' \\ B' & E_a - m_a^2/2E_a \end{pmatrix} \begin{pmatrix} A(z) \\ a(z) \end{pmatrix}$$

$$P_a(z) = |a(z)|^2 = \frac{B'^2}{q^2+\Gamma^2/4}\left[1 + e^{-\Gamma z} - 2e^{-\Gamma z/2}\cos(qz)\right]$$

$$P_\gamma(z) = |A(z)|^2 = e^{-\Gamma z}\left\{1 - \cancelto{0}{\frac{B'^2}{q^2+\Gamma^2/4} e^{\Gamma z/2}} \cos(qz) + \cancelto{0}{\mathcal{O}(B'^4)}\right\}$$

Photon in the dense plasma will be quickly absorbed.

The coherence length will depend on the path-length of the photon.

<u>Mean probability to convert a photon into axion</u>

In practice we just integrate the probability of a photon to reach a distance z by the conversion probability at z

$$P_{\gamma a} = \int_0^\infty P_\gamma(z) P_a(z) dz \longrightarrow \boxed{P_{\gamma a} = \frac{1}{6}\frac{B'^2}{q^2+\Gamma^2/4}}$$

Solar axion flux integration

Considering only the transversal component
we obtain the mean conversion probability
per photon integrated to 4π

$$P_{\gamma a} = \frac{1}{6} \; \frac{{B'_\perp}^2}{q^2 + \Gamma^2/4} = \frac{\pi^2}{96} \; \frac{{B'_o}^2}{q^2 + \Gamma^2/4}$$

photon irradiance in thermal equilibrium

$$\frac{d\phi_a}{dE} = \frac{1}{4\pi d_\odot^2} \int_{V_{Sun}} P_{\gamma a}\, d^3\mathbf{r}\, \frac{1}{(2\pi)^2} \frac{E^3}{e^{E/T} - 1}$$

Flux in
$cm^{-2}\ s^{-1}\ keV^{-1}$

Solar axion production in the Sun inner magnetic fields

S.Couvidat, S. Turck-Chieze, A. Kosovichev, APJ 599, 1434 (2003)

TABLE 4
MODELS WITH MAGNETIC FIELD

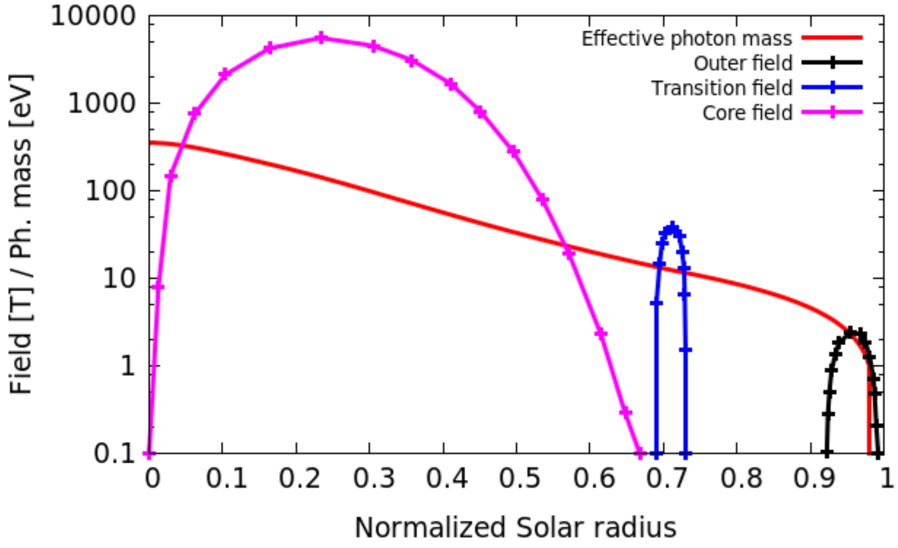
Name	B_0 (T)	Center[a] ($R_\odot$)	$(P_{mag}/P_{gas})_{max}$
~~Seismic$_1$B$_1$~~	~~10^4~~	~~0.236~~	~~2.85×10^{-2}~~
~~Seismic$_1$B$_{11}$~~	~~5×10^3~~	~~0.236~~	~~6.96×10^{-3}~~
~~Seismic$_1$B$_{12}$~~	~~3×10^3~~	~~0.236~~	~~2.49×10^{-3}~~
Seismic$_1$B$_{13}$	1×10^3	0.236	2.80×10^{-4}
Seismic$_1$B$_2$	30	0.712	6.15×10^{-5}
Seismic$_1$B$_{21}$	50	0.712	1.71×10^{-4}
Seismic$_1$B$_3$	2	0.96	1.34×10^{-4}
Seismic$_1$B$_{31}$	3	0.96	3.02×10^{-4}

[a] Radius at which P_{mag} is maximum.

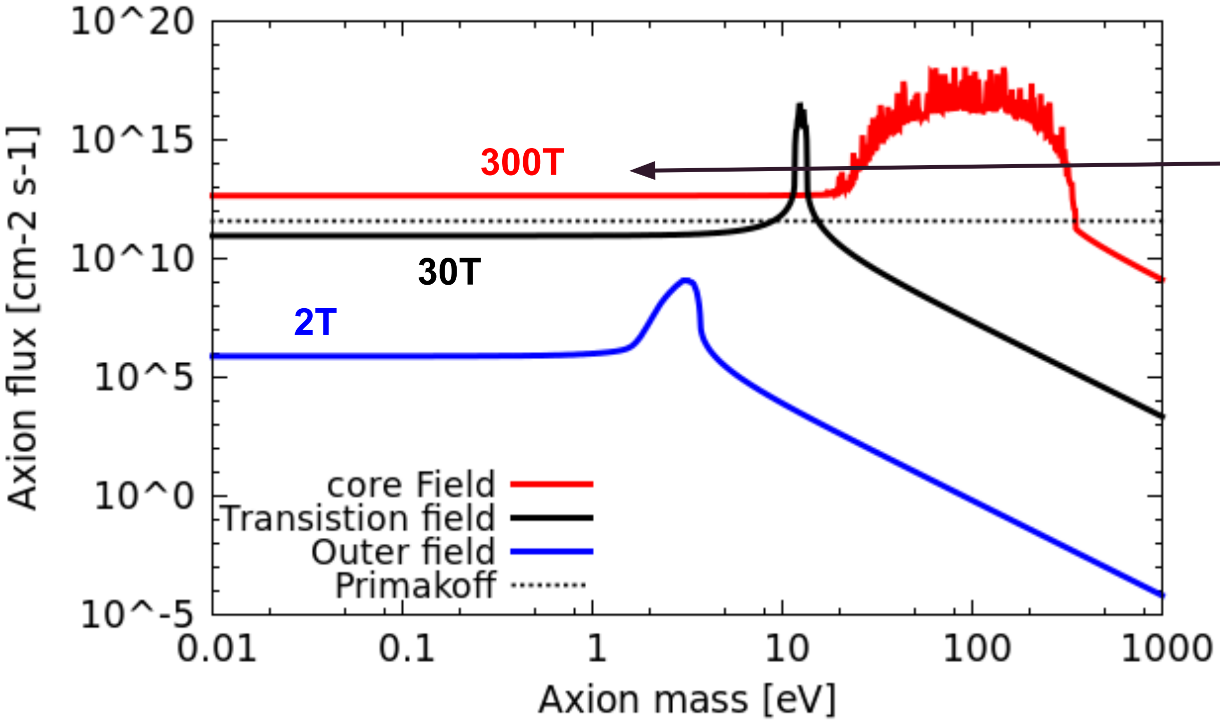
9). The precision we have on the solar sound speed rules out a magnetic field with such a profile and an intensity as large as $B_0 = 10^4$ T. Actually, we can put an upper limit for a (toroidal) magnetic field in the radiative zone of about 3×10^3 T (seismic$_1$B$_{12}$ model). If $B_0 \leq 10^3$ T, then c_s is not sensitive enough to P_{mag}, and we cannot draw any conclusion about

Assuming scattering factor for H f_1 = 1 and a purely Hydrogen Sun composition

$$m_\gamma \simeq 28.77\sqrt{\rho(r)[\mathrm{g/cm^3}]}\,\mathrm{eV}$$



Solar axion production in the Sun inner magnetic fields

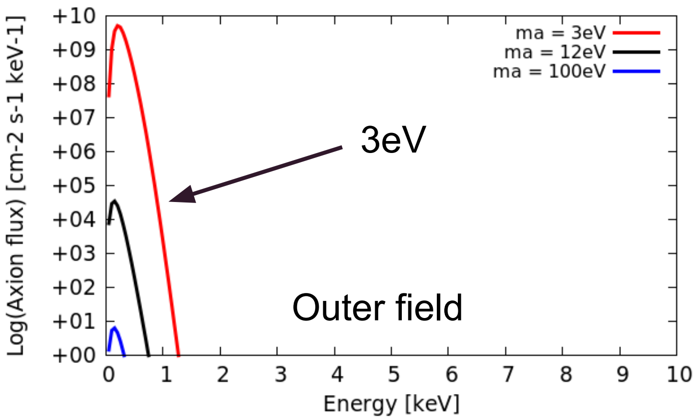


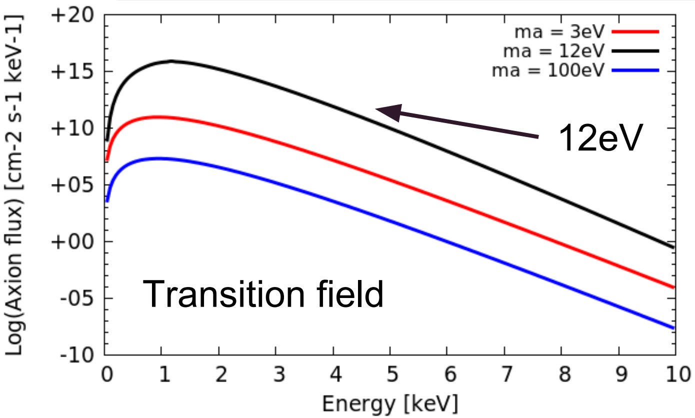
In the core **3000T are still allowed** without effect on Solar observables.

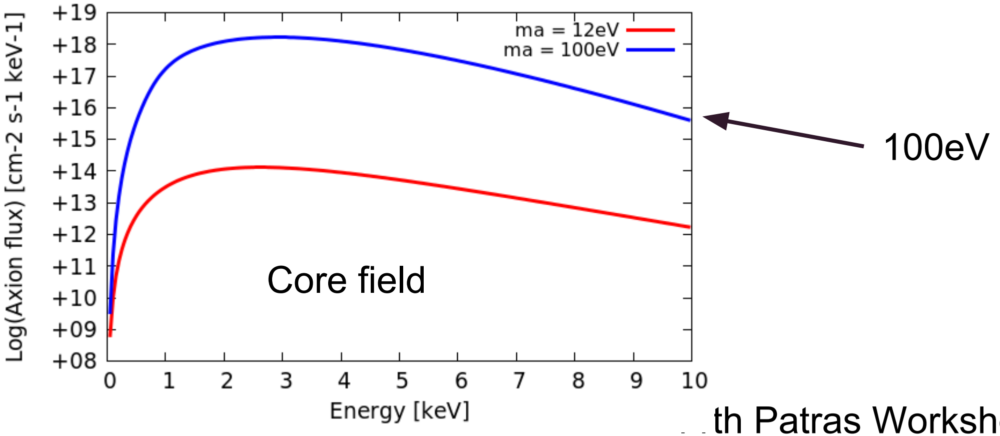
Calculation considering factor 10 reduction

300T

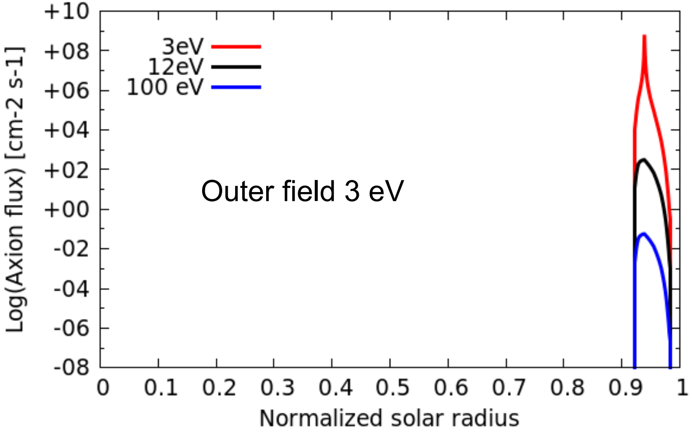
Solar axion spectrum generated by the different magnetic regions

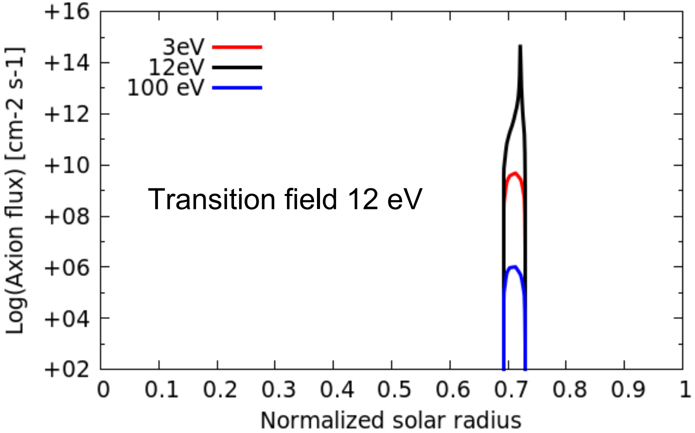


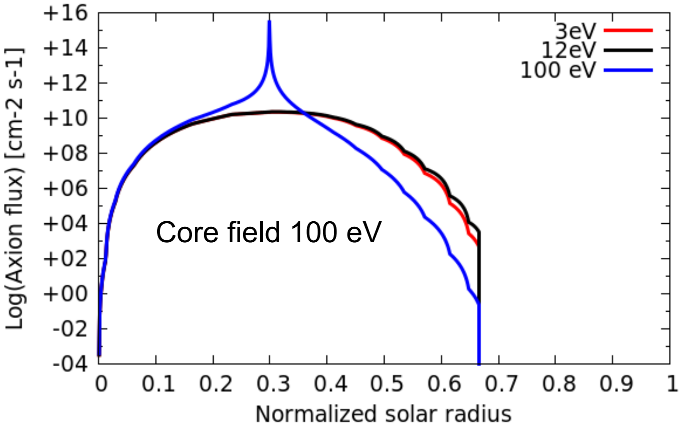




Differential axion flux production as a function of R



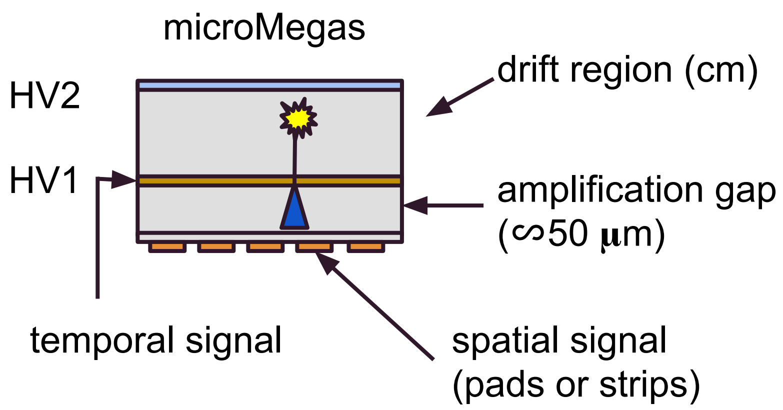




Spherical TPC Detection principle

Micromegas : Best results in terms of energy resolution and spatial resolution (few um)

Main advantage of micromegas is that amplification takes place in a **short amplification gap**



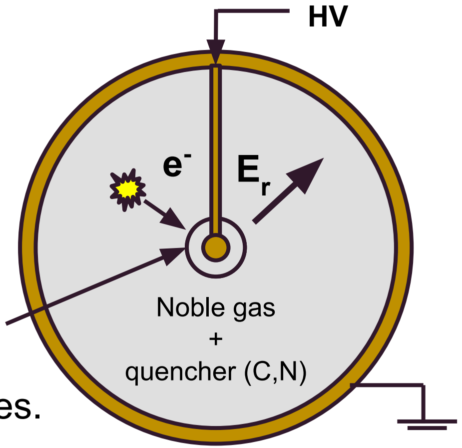
Micromegas : Amplification given by (HV1-HV2)/d

Spherical TPC : Amplification given by HV and Rsensor. Definition of amplification gap and drift region relays on **strong field variation near the sensor**.

Low noise (few eV)
Spherical geometry

Simplified read-out
price for decreased spatial resolution

Intense field.
Enough to produce avalanche processes.



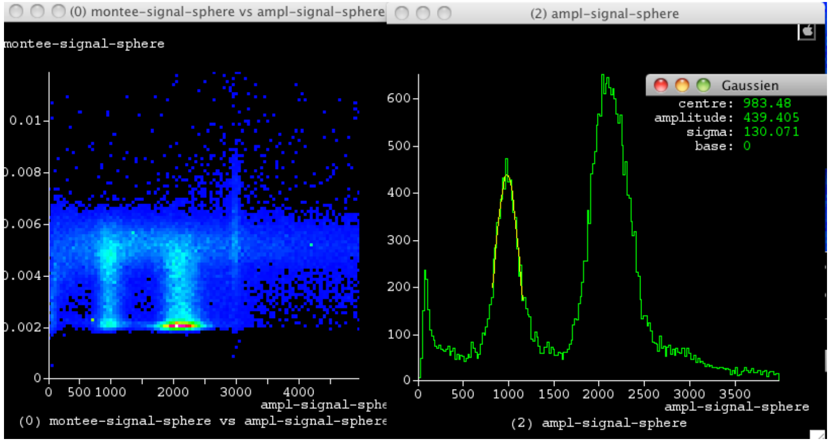
A spherical TPC for particle physics (neutrons, neutrinos, DM, ...)

Existing spheres running in ground and underground laboratories (NEWS collaboration)

- **Large volume**
- Simplified read-out
- **Gas pressure flexibility** : from few mbar to several bar
- Good energy resolution
- **Low energy threshold**
- Field cage and vessel are one single entity.

Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons $7\text{x}10^6$neutrons/s

Irradiation time 14 days. Ar-37 emits K(2.6 keV) and L(260 eV) X-rays (35 d decay time)



A spherical TPC for rare event searches (SEDINE)

SEDINE detector installed at Underground Modane Laboratory

Volume : 100 dm^3
Pressure : From few mbar to 10 bar
Gas : He, Ne, Ar, ...